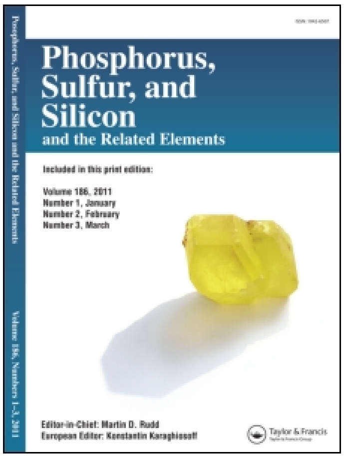

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METHODS FOR PREPARATION OF DISILATHIANES

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Several literature methods for preparation of disilathianes were reexamined and new procedures were developed. Two methods especially useful for the preparation of hexamethyldisilathiane were the reaction between lithium metal, sulfur, and TMS chloride in THF, and the reaction between Li_2S and TMS chloride in THF at room temperature. These two procedures may also be used to prepare other hexaalkyldisilathianes. Other methods investigated for the preparation of hexamethyldisilathiane included (a) reaction between commercial anhydrous Na_2S and TMS chloride in N,N′-dimethylpropyleneurea or HMPA, (b) production of a highly-reactive Na_2S by reaction between sodium dispersion and sulfur, followed by reaction with TMS chloride in THF at room temperature, and (c) reaction between sulfur, NaH, and TMS chloride in N,N′-dimethylpropyleneurea.

Keywords: Disilathianes; Chlorosilanes; Sodium sulfide; Lithium sulfide

INTRODUCTION

Disilathianes such as hexamethyldisilathiane (HMDT, **1a**) have wide utility as reagents in synthesis. For example, recently reported applications of HMDT in organic synthesis have included its use in the preparation of thiols,[1] in the conversion of acetals and aldehydes to thioxo derivatives,[2] in the reduction of aromatic azides to amines,[3] and as the starting material for the preparation of sodium trimethylsilanethiolate, a powerful nucleophile useful for the demethylation of aromatic methyl ethers, for the conversion of nitriles to thioamides and for the reduction of aromatic nitro compounds to amines.[4] HMDT has also been used extensively in inorganic synthesis for the preparation of compounds containing metal-sulfide

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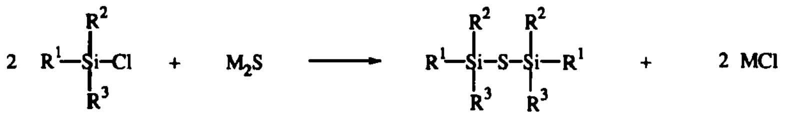
bonds.[5] In connection with recent studies in our laboratory which demonstrated the utility of HMDT for the preparation of 3*H*-1,2-dithiole-3-thiones,[6] large quantities of this reagent were needed. Although HMDT is commercially available, its high cost led us to consider preparing the quantities we needed. A number of published procedures were judged unsuitable at the outset, either because they involved reagents which were themselves expensive (e.g. lithium triethylborohydride,[7] N-trimethylsilylimidazole[8, 9]) or inconvenient to use (gaseous H_2S[8 – 10]), or were associated with other technical difficulties such as the use of vacuum lines or specialized pieces of equipment.[11] To avoid these difficulties, a search was made for better and more convenient methods for the large-scale preparation of HMDT and of other hexaalkyldisilathianes. The results of this investigation are reported herein.

RESULTS AND DISCUSSION

Preparation of HMDT from Na_2S and TMS Chloride

The straight-forward preparation of HMDT by reaction of anhydrous Na_2S with TMS chloride (Scheme 1, M = Na, $R^1 = R^2 = R^3 = Me$) appeared to suffer from two difficulties: This reaction was reported by Abel to proceed only at high temperature (250 °C),[12] and at the time our study was initiated anhydrous Na_2S was not commercially available. The second difficulty was overcome by dehydration of a sample of $Na_2S•9H_2O$ until the theoretical amount of water had been lost. Not surprisingly, given the report of Abel,[12] the resulting anhydrous Na_2S failed to react with TMS chloride in refluxing THF. However, addition of a dipolar aprotic solvent, either HMPA or the less toxic N,N′-dimethylpropyleneurea (DMPU), led to a rapid reaction at room temperature. A typical reaction in a two phase mixture of hexane and DMPU gave HMDT in 58% yield, as determined by GC of the crude reaction mixture. However, the mixture also contained 27% of hexamethyldisiloxane **2a**. It is likely that **2a** arose either from incomplete dehydration of the Na_2S or from sodium hydroxide present in the starting material or formed during the drying process. A repeat of this reaction in THF-DMPU solvent using commercial anhydrous Na_2S claimed to assay at better than 98% gave somewhat better results. GC analysis showed a mixture consisting of 77% HMDT and 17% siloxane **2a**. Since the same batches of THF, DMPU, and TMS chloride were used for preparation of HMDT by other procedures without formation of such large amounts of siloxane (*vide infra*), it seems likely that the commercial sample of anhydrous Na_2S was also contaminated with water and/or sodium hydroxide. As shown by further experiments described below, isolation of HMDT from this reaction mixture by fractional distillation should have been possible but was not actually carried out.



$$2\ R^1R^2R^3Si{-}Cl + M_2S \longrightarrow R^1R^2R^3Si{-}S{-}SiR^1R^2R^3 + 2\ MCl$$

1a: $R^1 = R^2 = R^3 = Me$

1b: $R^1 = R^2 = R^3 = Et$

1c: $R^1 = R^2 = Me$; $R^3 = t\text{-}Bu$

1d: $R^1 = R^2 = R^3 = i\text{-}Pr$

SCHEME I

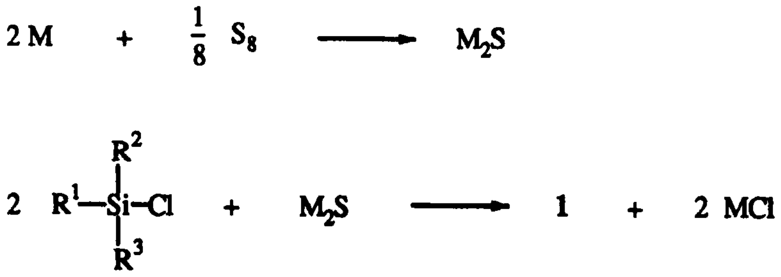
$R_3SiOSiR_3$

2a: R = Me

2b: R = Et

Preparation of HMDT from Sodium, Sulfur, and TMS chloride

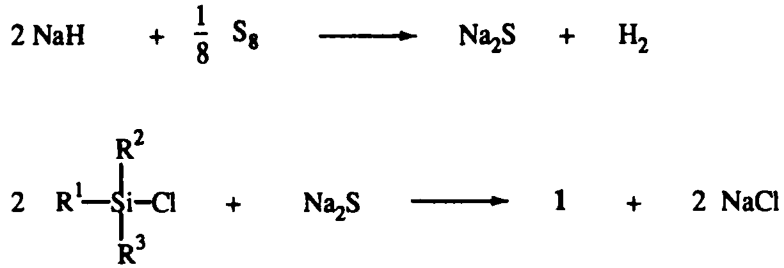
The experiments with Na_2S suggested that if a convenient procedure for the generation of truly anhydrous Na_2S could be developed, the sulfide should react with TMS chloride to produce HMDT in good yield. In this regard, the procedure of So and Boudjouk[13] appeared attractive. This procedure involves naphthalene-catalyzed reduction of elemental sulfur by metallic sodium in boiling THF, followed by reaction of the resulting Na_2S with TMS chloride. However, in our hands this procedure proved somewhat capricious, with the reduction by sodium often taking a prolonged time and/or being incomplete, resulting in a lowered yield of HMDT. In addition, as noted by So and Boudjouk,[13] the final product was contaminated by naphthalene.



SCHEME 2

As a way around these difficulties it was found (Scheme 2, M = Na, $R^1 = R^2 = R^3 =$ Me) that a commercially available sodium dispersion in mineral oil reacted vigorously with sulfur suspended in ice-cold THF. The resulting finely-divided Na_2S then reacted readily with TMS chloride at room temperature to produce HMDT in 81% chromatographic yield, with less than 2% siloxane **2a** being produced. Isolation of HMDT from this mixture initially presented some difficulty because the sodium chloride formed was extremely voluminous and tenaciously retained the disilathiane. The best procedure developed involved separation of crude HMDT from the inorganic byproduct by vacuum distillation, followed by redistillation at a higher pressure. A typical run on a 0.1 mole scale produced a 73% yield of HMDT. The failure of the reaction to proceed to completion was probably due to conversion of some of the sodium to the large unreactive aggregates which were recovered from the reaction mixture. Indeed, simple addition of THF to the sodium dispersion at room temperature converted it to a single lump of sodium metal, possibly because local heating was sufficient to melt the finely divided sodium. Although the reaction between the sodium dispersion and sulfur is quite vigorous, it can be readily controlled by dropwise addition of the metal dispersion to an ice-cold sulfur suspension. Thus preparation of HMDT on a scale larger than 0.1 mole by this method should present no difficulties.

Two other methods for the preparation of anhydrous Na_2S, while less convenient, also provided HMDT in usable yields. First, the sodium dispersed in mineral oil could be replaced by sodium dispersed in paraffin. However, the resulting Na_2S was less reactive than that produced by the mineral oil dispersion and reacted only slowly with TMS chloride in refluxing THF. As expected, addition of DMPU greatly accelerated the reaction, but the chromatographic yield reached a maximum of only 70% and the method seemed to offer no advantage over that employing the mineral oil dispersion. Second, molten sodium and sulfur reacted in refluxing dioxane to give a Na_2S which when treated with TMS chloride at reflux produced a 68% chromatographic yield of HMDT. However, the lower yield and need to separate the HMDT from the higher boiling dioxane as compared to THF makes this procedure less attractive than the sodium dispersion method.



$$2\,NaH + \frac{1}{8}S_8 \longrightarrow Na_2S + H_2$$

$$2\,R^1R^2R^3Si{-}Cl + Na_2S \longrightarrow \mathbf{1} + 2\,NaCl$$

SCHEME 3

Preparation of HMDT from NaH, Sulfur, and TMS Chloride

As an alternative to the use of a sodium dispersion, it was of interest to investigate whether the cheap and readily available NaH could function as a reductant toward sulfur, as outlined in Scheme 3. Surprisingly, the literature contains little information on the reaction between NaH and sulfur,[14] so this point seemed to be of some intrinsic interest in itself. In the event, NaH and sulfur were found to react to only a small extent in THF at room temperature as judged by measurement of the amount of hydrogen evolved. Heating to reflux produced more hydrogen but the total evolved corresponded to only about one-third of that calculated for complete reduction of elemental sulfur to sulfide. Addition of TMS chloride to this mixture brought about formation of HMDT in a maximum chromatographic yield of 60%, accompanied by yet more hydrogen evolution. The vigorous gas evolution which occurred when a small amount of methanol was then added to the final reaction mixture suggested that the low yield of HMDT obtained was due to the presence of unreacted hydride, possibly because of coating by the sodium chloride byproduct. A change to DMPU as reaction solvent solved this difficulty. The reaction between NaH and sulfur in DMPU at room temperature again evolved only 14% of the theoretical amount of hydrogen. However, upon slow addition of TMS chloride the remainder of the theoretical amount of hydrogen was evolved and HMDT was formed in greater than 90% chromatographic yield. HMDT may then be isolated from the reaction mixture by simple vacuum distillation. A reaction run in this way on a 0.2 mole scale gave a 90% yield of HMDT. The preparation required only a minimum amount of expensive DMPU solvent, 60% of which was recovered by vacuum distillation of the residue remaining after removal of HMDT. This procedure is fast, cheap, and amenable to large scale preparation of HMDT.

Preparation of Hexaalkyldisilathianes from Lithium, Sulfur, and Silyl Halides

As mentioned above, the preparation of HMDT via Scheme 2 using sodium metal in the presence of a catalytic amount of naphthalene suffered from contamination of the product by the catalyst.[13] It appeared that this problem might be avoided by effecting the reduction of sulfur with lithium rather than sodium, substituting the much less volatile 4,4′-di-*tert*-butylbiphenyl (DTBB) for naphthalene. The combination of lithium-DTBB is finding increasing use in organic chemistry.[15] Indeed, when lithium powder was stirred with 5 mole % DTBB in THF until the deep blue color of the radical anion was well developed and a stoichiometric amount of sulfur then added, all the sulfur dissolved to form a deep red-brown solution. However, considerable unreacted lithium metal was still present. Slow addition of TMS chloride to this mixture led to dissolution of the remainder of the lithium and to formation of HMDT in 86% chromatographic yield. While this result appeared very promising, the fact that much lithium remained unreacted until the silyl chloride was added, and that in a separate experiment addition of DTBB to a mixture of sulfur and lithium in THF did *not* lead to any reaction, raised the question of what role the DTBB was actually playing. The answer to this question was provided by an experiment in which a small amount of TMS chloride was added to a stirred mixture of sulfur and lithium in THF. After a brief induction period, a rapid exothermic reaction ensued, signalled by the development of a red-brown color in the solution immediately surrounding the lithium particles. All the sulfur went into solution, accompanied by only part of the lithium, to yield the same red-brown mixture obtained in the presence of DTBB. Slow addition of TMS chloride then produced HMDT in nearly quantitative yield. Clearly DTBB was not essential to the reaction.[16] Experiments showed that as little as 0.5 mole % of TMS chloride would initiate the reaction. Furthermore, it was not necessary to use lithium in the form of the highly reactive powder. Lithium shot and even small pieces of 3.2 mm diameter wire worked equally well. Using lithium shot, HMDT was prepared on a 0.5 mole scale in 78% isolated yield. An additional advantage of this procedure as compared to those involving sodium, was that the lithium chloride byproduct was far less voluminous than sodium chloride, facilitating isolation of the HMDT by direct distillation of the reaction mixture.

The rapidity with which this reaction occurred, the absence of a requirement for a high-boiling additive such as DMPU which might interfere with product isolation, and the ease with which the HMDT could be isolated from the reaction mixture, suggested that the procedure might be useful for the preparation of other hexaalkyldisilathianes. This indeed proved to be the case, with the hexaalkyldisilathianes **1b**, **1c**, and **1d** being prepared in 77, 84, and 57% yields, respectively. In general, it was observed that the more hindered the silyl chloride, the longer the induction period for the lithium-sulfur reaction and the slower the chloride had to be added to obtain a good yield. Use of lithium powder rather than shot shortened the silyl chloride addition time, especially with the more hindered silyl chlorides such as TIPS chloride and TBDMS chloride. The somewhat lower yield obtained for **1d** was attributed to mechanical losses during distillation caused by the high boiling point and viscosity of this material, and to the formation of byproducts not found in preparation of the other hexaalkyldisilathianes. These byproducts were identified by GC/MS as the polysulfides **3**.

$$(i\text{-}Pr_3Si)_2S_n$$

3: n = 2 - 4

In considering possible mechanisms for this reaction, the following observations must be accommodated: (1) An experiment was carried out in which 1 mole % of TMS chloride was added to a THF suspension of lithium shot and sulfur in a 2:1 g atom ratio. The reaction was allowed to proceed until all the sulfur had dissolved to give the usual red-brown solution and then the unreacted lithium was recovered and weighed. Approximately 0.4 g atom of lithium per g atom of sulfur was found to have reacted. Thus the average composition of the red-brown polysulfide solution, which may be a mixture, corresponded to approximately Li_2S_5. (2) During subsequent addition of silyl chloride to the polysulfide solution, if the silyl chloride is added too rapidly the dark color fades completely. Pausing the addition of the silyl chloride at this point may result in a reappearance of the dark coloration. However, if this does not happen, then further addition of silyl chloride does not produce more hexaalkyldisilathiane **1** and the reaction has clearly stopped. Thus maintenance of a dark coloration during the course of silyl chloride addition seems to correlate with the success of the reaction. (3) In reactions which had halted because of too rapid addition of silyl chloride, the unreacted lithium particles were found to be coated with a white crystalline solid. (4) With the highly hindered TIPS chloride, polysulfides **3** were detected as reaction byproducts. In explaining the above observations, it should be kept in mind that after initiation of the reaction between lithium and sulfur by a catalytic amount of silyl chloride, *all* of the sulfur is in solution, so that the subsequent reaction consists only in reductive degradation of the initially formed polysulfide by the combination of metallic lithium and silyl chloride as shown in eq 1 (for the sake of definiteness the polysulfide initially formed is assumed in eq 1 to be the pentasulfide).

$$10\ R_3SiCl\ +\ 8\ Li\ +\ Li_2S_5\ \longrightarrow\ 5\ (R_3Si)_2S\ +\ 10\ LiCl \qquad (1)$$

The question then becomes the sequence of steps by which this transformation occurs. One plausible sequence is shown in Scheme 4. The lithium polysulfide **4** would be expected to react rapidly with silyl chloride (eq 2), forming the monosilylated intermediate **5**. Intermediate **5** might then be expected to react in two ways. Reduction of a disulfide bond in **5** by lithium would convert it to a lower silylated polysulfide **6** and a lower lithium polysulfide **7** (eq 3). Alternatively (eq 4), **5** might undergo a second silylation *before* reduction, producing the bissilylated intermediate **8**. Reduction of **8** by lithium would then result in a mixture of lower silylated polysulfides **9** and **10** (eq 5). The intervention of eq 4 is supported by the detection of the polysulfides **3** in the TIPS chloride reaction, where presumably steric hindrance slows up the reaction of eq 5 sufficiently that some intermediate **8** escapes reduction. It seems likely that the reduction of polysulfide **5** shown in eq 3 will tend to occur at the sulfur-sulfur bond most remote from the negative end of the polysulfide chain in order to minimize unfavorable charge-charge interactions. Thus m in equation 3 is likely to be 1, producing an intermediate **6** whose silylation gives the final hexaalkyldisilathiane product **1**, and reducing the number of sulfur atoms in **4** by one. In contrast, the reduction of eq 5 is likely to proceed at the most interior sulfur-sulfur bond, producing intermediates **9** and **10** in which n and m are as equal as possible. Regardless of the precise sequence, repetition of the reactions shown in eqs 2 – 5 will convert the mixture of polysulfide **4**, silyl chloride, and lithium to **1** and lithium chloride, as required by eq 1.

$$\underset{\mathbf{4}}{Li_2S_n} + R_3SiCl \longrightarrow \underset{\mathbf{5}}{R_3SiS_nLi} + LiCl \qquad (2)$$

$$2\,Li + \mathbf{5} \longrightarrow \underset{\mathbf{6}}{R_3SiS_mLi} + \underset{\mathbf{7}}{Li_2S_{n-m}} \qquad (3)$$

$$R_3SiCl + \mathbf{5} \longrightarrow \underset{\mathbf{8}}{(R_3Si)_2S_n} + LiCl \qquad (4)$$

$$2\,Li + \mathbf{8} \longrightarrow \underset{\mathbf{9}}{R_3SiS_mLi} + \underset{\mathbf{10}}{R_3SiS_{n-m}Li} \qquad (5)$$

SCHEME 4

The inhibitory effect of allowing excess silyl chloride to accumulate can be understood by considering the reactions occurring at the lithium surface, e.g. eqs 3 and 5. It seems likely that the products of these reductions, the polysulfides **6**, **7**, **9** and **10**, will be initially bound to the surface of the lithium metal. In the presence of high concentrations of silyl chloride these ionic species may not have time to diffuse from the surface into the bulk medium before reacting with the silyl chloride to form lithium chloride. Crystallization of this on the lithium surface, which may account for the crystalline deposit observed in reactions which have prematurely halted, could then block access of further reactants to the lithium metal. The highly colored intermediates formed in the course of the reaction, presumably polysulfides **4** – **7**, **9** and **10**, serve as visual indicators of the concentration of silyl chloride in solution. When silyl chloride concentration is high, concentrations of the polysulfides will be low, since their silylation would be expected to be rapid, and conversely. Reappearance of the colored species after bleaching by excess silyl chloride is explained by the operation of eq 5, which will generate **9** and **10** as long as access to the lithium surface has not been completely blocked by salt crystallization. Although intimate details of some of the steps remain unknown, Scheme 4 does seem to provide an adequate framework for understanding observations made during the course of the preparation.

Preparation of Hexaalkyldisilathianes from Li_2S and Chlorosilanes

There is contradictory information in the literature concerning the reaction of Li_2S with TMS chloride. Olah[17] reported that no reaction occurs between Na_2S or Li_2S and TMS chloride at room temperature and pressure, citing the work of Abel.[12] However, Abel examined only Na_2S, not Li_2S, in this reaction. Detty and Seidler[7] also cited Abel's paper as indicating that the reaction between Li_2S and TMS chloride occurred only at high temperature and pressure. However, Detty and Seidler reported finding that the reaction did take place in refluxing THF to produce HMDT in 45% yield after 72 h.[7] More recently Band and Eberhart[18] claimed in a patent the preparation of HMDT in quantitative yield by stirring and refluxing Li_2S with TMS chloride in acetonitrile for a total of about 70 h. To clear up this confusion we have reexamined the reaction of commercially available anhydrous Li_2S with TMS chloride under various conditions. The results are shown in the first six entries of Table I.

In order to compare rates under different conditions, the time the reaction took to reach a 50% yield of hexaalkyldisilathiane, designated as t_{50}, was measured by interpolation on a plot of yield versus time. This empirical measure was used because the reactions, which were heterogenous and run in concentrated solution, did not appear to follow any simple rate law. As shown in the first entry of Table I, the reaction between Li_2S and TMS chloride proceeded smoothly in THF at room temperature. After 24 h the yield of HMDT had leveled off at 90%. Of some interest, in view of the report of Detty and Seidler,[7] was that refluxing the reaction mixture (Entry 2) had only a small effect on reaction rate. Entry 3 shows that increasing the concentration of TMS chloride actually decreased the rate slightly, undoubtedly due to the rather large change in the medium which occurred when the concentration of TMS chloride was increased. The use of acetonitrile (Entry 4), as described by Band and Eberhart,[18] seemed to offer no particular advantage, with the rate in this solvent being similar to that in THF. Acetonitrile has the disadvantage of a higher boiling point, greater toxicity, and difficulty of drying as compared to THF. Reaction in DMPU (Entry 5) was, as expected, much faster than in any other solvent examined but from a practical standpoint offered no advantage over THF. Finally, the two components did not react in the absence of a solvent (Entry 6). On a 0.2 mole scale, stirring stoichiometric amounts of Li_2S and TMS chloride in THF for 24 h at room temperature, followed by simple fractional distillation, gave HMDT in 83% yield. This very simple procedure for the preparation of HMDT using only commercially available starting materials (including anhydrous THF) was the simplest to carry out of the several investigated. It should be amenable to reaction on any scale and has as its only disadvantage the somewhat higher cost of Li_2S as compared to other sulfide sources.

TABLE I Reaction of Lithium Sulfide with Chlorosilanes

entry	*chlorosilane*	*solvent*	*temperature*	*concn*[a]	t_{50}[b] *(h)*
1	Me_3SiCl	THF	Room	5	1.5
2	Me_3SiCl	THF	Reflux	5	1.1
3	Me_3SiCl	THF	Room	10	2.3
4	Me_3SiCl	MeCN	Room	5	2.0
5	Me_3SiCl	DMPU	Room	5	<1
6	Me_3SiCl	None	Room		NR
7	Et_3SiCl	THF	Room	5	3.5
8	Et_3SiCl	THF	Reflux	5	2.2
9	Et_3SiCl	THF	Room	10	6.9
10	Et_3SiCl	MeCN	Room	5	16
11	Et_3SiCl	MeCN	Reflux	5	1.0
12	Et_3SiCl	DME	Room	5	2.0
13	Et_3SiCl	DME	Room	10	2.6
14	Et_3SiCl	Dioxane	Room	5	44
15	t-$BuMe_2SiCl$	DME	Room	10	33
16	i-Pr_3SiCl	DME	Room	5	360
17	i-Pr_3SiCl	DME	Reflux	5	160

a. Moles chlorosilane per liter of solvent.

b. Time for reaction to reach 50% completion.

The remaining entries in Table I show the utility of this procedure for the preparation of other hexaalkyldisilathianes. Under comparable conditions the more hindered chlorotriethylsilane appeared to react at about half the rate of TMS chloride (Entries 1 versus 7, 2 versus 8, and 3 versus 9). A marked solvent effect was also noted (Entries 7, 10, 12, and 14), with the rate order being DME > THF > acetonitrile > dioxane. For DME, THF, and dioxane it may be that the observed order is related to the solubility of Li_2S in the respective solvents, although this was not determined directly. The much larger rate difference between THF and acetonitrile as solvents when the substrate was chlorotriethylsilane (Entry 7 versus 10) as compared to TMS chloride (Entry 1 versus 4) arose from the insolubility of chlorotriethylsilane in acetonitrile at room temperature, another disadvantage to the use of acetonitrile as solvent. The small dependence of the rate of reaction on temperature observed for TMS chloride in THF was also observed for chlorotriethylsilane in THF (Entry 7 versus 8) and for TIPS chloride in DME (Entry 16 versus 17). In addition, the last pair of reactions showed a marked contrast in kinetic behavior. The reaction at room temperature (Entry 16) appeared to proceed at a constant rate, i.e. zero order in product formation, to well beyond 60% yield of **1d**, eventually reaching 87% yield after 800 h. In contrast, the reaction at reflux (Entry 17), while initially much faster, showed a rate which continually declined with time until product formation finally leveled off at a 55% yield of **1d**, the remainder of the silyl chloride remaining unreacted. This behavior suggests a temperature dependent inhibition of the reaction, possibly arising from surface changes in the insoluble Li_2S. The large dependence of rate on temperature observed for chlorotriethylsilane in acetonitrile (Entry 10 versus 11) was likely due to the marked increase in the solubility of this silane in acetonitrile as the temperature was raised. The rate retarding effect of increased silane concentration noted for TMS chloride in THF was also noted for chlorotriethylsilane in THF and DME (Entries 7 versus 9 and 12 versus 13). As expected, the rate of the reaction of Li_2S with different silyl chlorides under comparable conditions followed an order determined by steric hindrance, with chlorotriethylsilane > TBDMS chloride > TIPS chloride (Entries 13, 15, and 16). In summary, the data in Table I suggest a reaction not markedly affected by temperature or concentration of silyl chloride, but somewhat more sensitive to changes in solvent, with DME being an especially useful solvent for hindered silanes. In reactions carried out for preparative purposes using DME solvent at room temperature, a 92% yield of **1b** was isolated after 24 h, a 71% yield of **1c** after 110 h, and a 61% yield of **1d** after 833 h.

CONCLUSION

HMDT **1a** may be prepared economically and on a large scale by any of the several procedures investigated here, of which the reaction between Li_2S and TMS chloride in THF, or between lithium, sulfur, and TMS chloride in THF are especially easy and inexpensive to carry out. These two procedures may also advantageously be used for the preparation of the higher disilathianes **1b** – **1d**, although prolonged reaction periods and the use of DME solvent may be necessary in the case of highly hindered disilathianes such as **1d**. Preparations of HMDT involving sodium plus sulfur, NaH plus sulfur, or anhydrous Na_2S, while more economical in some cases, are somewhat more tedious because of the voluminous nature of the sodium chloride byproduct which complicates workup of the reaction mixtures.

EXPERIMENTAL

General

All reactions were conducted under an atmosphere of dry argon. Reagents and reaction solvents were purchased from Aldrich Chemical Company, except for sodium dispersed in mineral oil (Alfa), TMS chloride (Fluka), sulfur (precipitated, Fluka), DMPU (Fluka), and chlorotriethylsilane (PCR). DMPU and HMPA were dried by distillation from CaH_2 and stored over 3A molecular sieves. Other reagents and solvents were used as received. GC analyses were conducted on a Varian Model 3500 gas chromatograph equipped with an FID, a split-splitless injector, and an SPB-1 fused silica column (30 m × 0.25 mm, Supelco, Inc.). Quantitation was either by the use of dodecane as an internal standard or, since most reaction mixtures contained only chlorosilane, disilathiane **1**, and siloxane **2**, by converting the areas of these three components to relative amounts using the appropriate sensitivity factors and then scaling the relative amounts so that their sum equaled the amount of silyl chloride originally taken. The two methods of quantitation agreed within a few percent when applied to the same mixture.

CAUTION: Disilathianes and HMDT in particular have a noxious odor and are probably toxic. All preparations and handling of these compounds should be done in a well-ventilated fume hood. All equipment coming in contact with the disilathianes as well as all reaction residues should be treated with hypochlorite solution (household bleach) prior to removal from the hood.

Reaction of Na_2S with TMS Chloride

A sample of $Na_2S•9H_2O$ (40.8 g, 0.17 mol) was dried 2 d in a vacuum desiccator over Drierite. The resulting solid was ground under argon in a glove bag, returned to the vacuum desiccator for one more day, then dried *in vacuo* at 140 °C to constant weight over P_4O_{10}. This required 2 d. A total of 26.7 g water (97% of theory) was lost. The resulting solid was stored in a vacuum desiccator over Drierite. An aliquot of this solid (472 mg, 6 mmol) was weighed in a glove bag under argon into a side-arm flask fitted with rubber septum and stopper and containing a magnetic stirring bar. The flask was removed from the bag and the stopper quickly replaced with a condenser connected to a source of dry argon. The solid was suspended in dry hexanes (6 mL), TMS chloride (1.6 mL, 12 mmol) and dodecane (0.69 mL, 3 mmol) added, followed by DMPU (1.1 mL). The mixture was stirred vigorously at room temperature and sampled periodically for GC analysis. After 3 h, the reaction mixture consisted of HMDT (58%), siloxane **2a** (27%) and unreacted TMS chloride (16%). The composition remained unchanged during an additional 6 h of stirring.

A similar reaction using commercial anhydrous Na_2S (0.78 g, 10 mmol), TMS chloride (2.5 mL, 20 mmol) in DMPU (1 mL) and anhydrous THF (3 mL) containing dodecane (0.57 mL, 2.5 mmol) in which the TMS chloride was added dropwise over 80 min to the mechanically-stirred sulfide suspension gave a mixture consisting of HMDT (81%), siloxane **2a** (18%) and unreacted TMS chloride (2%) when sampled 15 min after completion of TMS chloride addition.

Preparation of HMDT (1a) from NaH, Sulfur, and TMS Chloride

CAUTION: The initial reaction between NaH and sulfur as well as the subsequent addition of TMS chloride are strongly exothermic and evolve large quantities of flammable hydrogen gas. Suitable precautions should be taken to control both heat and gas evolution and the reaction should be run behind a safety shield. The reaction was conducted in a 500 mL round-bottom flask fitted with thermometer, pressure-equalized dropping funnel, mechanical stirrer with Teflon paddle and vacuum bearing, and condenser connected to a source of dry argon. A suspension of NaH (17.6 g of a 60% mineral oil dispersion, 0.44 mol) in dry DMPU (50 mL) was cooled and stirred in an ice bath until its internal temperature reached 2 °C. Finely-ground sulfur (6.41 g, 0.20 g atom) was then added in several small portions and the mixture allowed to warm to room temperature with occasional cooling to control the resulting exotherm and gas evolution. When gas evolution had ceased (about 30 min after reaching room temperature), the flask was again immersed in the ice bath and TMS chloride (63 mL, 0.5 mol) was added dropwise over a 4 h period, the ice bath being removed after 2 h. The reaction mixture was then allowed to stir overnight. The flask was fitted with a short Vigreaux column, the pressure lowered to 10 Torr and the flask contents stirred and heated to 130 °C while collecting the distillate in a receiver cooled to –78 °C. Redistillation of the receiver contents through a short Vigreaux column gave HMDT (32.3 g, 90%), bp 76–77 °C/43 Torr (lit.[13] bp 91–95 °C/100 Torr). Analysis by GC showed TMS chloride (0.1%) and siloxane **2a** (0.6%) as the only impurities. By lowering the pressure in the reaction flask, DMPU (32 mL, 64%) boiling at 67–68 °C/0.2 Torr was recovered in a purity suitable for reuse in the reaction.

When the reaction was conducted as above with 5 mg atom sulfur, 10.5 mmol NaH, and 10.5 mmol TMS chloride in an apparatus in which the condenser could be connected via a 3-way stopcock either to a source of dry argon or to a gas burette filled with mineral oil, the reaction between NaH and sulfur evolved a total of 16 mL gas at STP or 14% of theory, assuming reaction according to Scheme 3. After addition of TMS chloride, the total gas evolved was 121 mL at STP or 108% of theory.

Preparation of HMDT (1a) from Sodium, Sulfur, and TMS Chloride

CAUTION: The reaction between sodium and sulfur is strongly exothermic. A suspension of finely-ground sulfur (3.85 g, 0.12 g atom) in dry THF (40 mL) was stirred mechanically at 0° C while sodium dispersion (11.5 g of 40% in mineral oil, 0.2 g atom) was added dropwise over a 35 min period. After an additional 25 min at 0 °C, TMS chloride (32 mL, 0.25

mol) was added over a 15 min period and the mixture then stirred at room temperature overnight. A Claisen adapter was fitted to the flask and the bulk of the THF was removed at atmospheric pressure in an argon atmosphere. The pressure was then lowered to 0.5 Torr and all volatiles were collected in a flask cooled to – 78 °C (bath temperature 70 °C to 185 °C). Redistillation of the trap contents through a short Vigreaux column gave HMDT (13.1 g, 73%), bp 71–72 °C/34 Torr. Analysis by GC showed 99.6% HMDT, with small amounts of THF, TMS chloride and siloxane **2a** as the only impurities.

Preparation of HMDT (1a) from Lithium, Sulfur, and TMS Chloride

CAUTION: Once initiated, the reaction between lithium and sulfur is strongly exothermic. The minimum amount of TMS chloride necessary to initiate the reaction should be used and the process should be closely monitored by measurement of the temperature of the reaction mixture. The reaction was conducted in a 500 mL round-bottom flask fitted with thermometer, pressure-equalized dropping funnel, mechanical stirrer with Teflon paddle, and condenser connected to a source of dry argon. The reaction flask was charged with finely powdered sulfur (16 g, 0.5 g atom), anhydrous THF (100 mL) was added, and the suspension was cooled and stirred in an ice bath. Lithium metal (6.94 g, 4 to 16 mesh, 1 g atom) was added and the dropping funnel was charged with TMS chloride (127 mL, 1 mol). When the internal temperature had reached 1 °C, 5 drops (approximately 0.14 mL) of the chlorosilane were added. Over a 3 min period the color of the suspension turned a deeper orange but the internal temperature remained at 1 °C. An additional 6 drops of TMS chloride were added. Over the next 5 min, the color again deepened, but the internal temperature did not increase. Eleven more drops of silyl chloride were then added (total = ca 0.6 mL) whereupon a strong exotherm set in almost immediately. The internal temperature rose to 17 °C over a period of 5 min, the mixture turned a deep red-brown color, and the sulfur completely dissolved. When the internal temperature had again fallen to 4 °C, dropwise addition of the TMS chloride was commenced. During this phase of the reaction, the rate of TMS chloride addition was adjusted such as to keep the temperature of the reaction mixture below 15 °C. At intervals chlorosilane addition was stopped, the ice bath removed, and the internal temperature monitored to see if the reaction was still proceeding exothermically.

After approximately one-third of the TMS chloride had been added, cooling in an ice bath was no longer necessary to control the reaction. The rate of TMS chloride addition was then adjusted so that the internal temperature slowly rose to 50 °C. The rate of addition was kept slow enough that the color of the mixture remained a deep red-brown. After approximately two-thirds of the chlorosilane had been added, the internal temperature began to drop and the rate of addition had to be decreased in order to maintain the deep red-brown color of the reaction mixture. During the last phase of the reaction, addition of the chloride was stopped periodically to allow the red-brown color to redevelop. The last 10% of the chloride solution was added at a rate of 1–2 drops per min when the color changes became so subtle that they could no longer be used to monitor the course of the reaction. Addition of TMS chloride required a total of 11 h. After stirring the mixture overnight, the flask was fitted with a Claisen adapter and THF was removed at atmospheric pressure under argon. The residue in the flask was then distilled under vacuum to give HMDT (70 g, 78%), bp 73–74 °C/43 Torr. Analysis by GC showed 99.4% HMDT, with small amounts of THF, TMS chloride and siloxane **2a** as the only impurities.

Preparation of Hexaethyldisilathiane (1b) from Lithium, Sulfur, and Chlorotriethylsilane

The reaction was conducted in a 50 mL flask fitted with a Hershberg stirrer, a rubber septum, and a condenser connected to a source of dry argon. To a suspension of finely-powdered sulfur (1.60 g, 50 mg atom) in dry THF (10 mL) was added lithium powder (0.80 g, 115 mg atom). A syringe containing chlorotriethylsilane (16.0 mL, 100 mmol) was mounted in a syringe pump and connected to the reaction flask via a Teflon needle inserted through the rubber septum. A portion of the silyl chloride (0.8 mL) was added to the rapidly stirred reaction mixture. After an induction period of about 4 min the reaction commenced, as indicated by the development of a red-brown color and an increase in temperature. The resulting exothermic reaction was controlled by occasional application of an ice bath in order to hold the temperature at slightly above room temperature. Fifteen min after initiation all the sulfur had dissolved to give a deep red brown mixture and the reaction was no longer evolving heat. Continuous addition of the chlorosilane was started, with the rate being adjusted such that a deep red brown color was maintained in the mixture for as long as possible, as described for the preparation of HMDT above. Chlorosilane addition required 9 h. After stirring overnight, the flask was fitted with a small vacuum-jacketed Vigreaux column and the THF removed by distillation under argon. The pressure was then lowered and after a small fore-run consisting principally of siloxane **2b**, hexaethyldisilathiane (**1b**) was collected as a clear colorless oil (10.2 g, 77%), bp 78–82 °C/0.02 Torr (lit.[20] bp 99–100°C/2 Torr); ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.76 (q, *J* = 7.5 Hz, 12H), 1.02 (t, *J* = 7.5 Hz, 18H); ^{13}C NMR (75.4 MHz, $CDCl_3$) δ 7.56, 8.10. Analysis by GC showed 98.9% purity.

1,3-Di-t-Butyl-1,1,3,3-tetramethyldisilathiane (1c) from Lithium, Sulfur, and TBDMS Chloride

This compound was prepared by the same procedure as for **1b** from sulfur (0.80 g, 25 mg atom) and lithium powder (0.40 g, 57.5 g atom), suspended in THF (7.5 mL) to which was added TBDMS chloride (7.54 g, 50 mmol) dissolved in THF (5 mL) over a period of 16 h. Disilathiane **1c** was obtained as a clear colorless oil (5.49 g, 84%), bp 62–64 °C/0.01 Torr, solidifying to a white solid, mp 40–41 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.31 (s, 12H), 0.99 (s, 18H); ^{13}C NMR (75.4 MHz, $CDCl_3$) δ 0.08, 19.37, 26.32. Analysis by GC showed 98.9% purity.

Hexaisopropyldisilathiane (1d) from Lithium, Sulfur, and TIPS Chloride

This compound was prepared by the same procedure as for **1b** from sulfur (0.80 g, 25 mg atom) and lithium powder (0.42 g, 60 g atom), suspended in THF (10 mL) to which was added TIPS chloride (10.7 mL, 50 mmol) dissolved in THF (5 mL) over a period of 16 h. Disilathiane **1d** was obtained as a clear colorless oil (5.09 g, 57%), bp 108–110 °C/0.06 Torr, solidifying to a white solid, mp 38–39°C (lit.[19] mp 36°C); ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.15 (d, *J* = 5.4 Hz, 36H), 1.2 – 1.3 (m, 6H); ^{13}C NMR (75.4 MHz, $CDCl_3$) δ 15.43, 19.13. Analysis by GC showed 97.2% purity.

Preparation of HMDT (1a) from Li_2S and TMS Chloride

To a magnetically-stirred suspension of anhydrous Li_2S (9.19 g, 0.20 mol) in anhydrous THF (40 ml) was added TMS chloride (50.8 mL, 0.40 mol).

The mixture was stirred under dry argon for 25 h, at which point GC analysis of an aliquot of the supernatant liquid showed HMDT **1a** (87%), siloxane **2a** (4.1%) and unreacted TMS chloride (9.2%). The reaction flask was fitted with a small vacuum-jacketed Vigreaux column and the THF removed by distillation under argon. The pressure was then lowered and after a small forerun, HMDT (**1b**) was collected as a clear colorless liquid (29.7 g, 83%), bp 77–78 °C/43 Torr. Analysis by GC showed 99.3% HMDT, with 0.4% of siloxane **2a** as the major impurity.

Hexaethyldisilathiane (1b) from Li_2S and Chlorotriethylsilane

This compound was prepared as for HMDT above from anhydrous Li_2S (2.30 g, 50 mmol) and chlorotriethylsilane (16.8 mL, 100 mmol) in dry DME (10 mL) stirred magnetically under dry argon for 24 h. At this point, an aliquot of the supernatant liquid showed 4% unreacted chlorosilane. Workup of the reaction mixture as for HMDT gave **1b** (12.2 g, 92%), bp 73–80 °C/0.02 Torr. Analysis by GC showed a purity of 98.7%.

1,3-Di-t-Butyl-1,1,3,3-tetramethyldisilathiane (1c) from Li_2S and TBDMS Chloride

This compound was prepared as for HMDT above from anhydrous Li_2S (1.15 g, 25 mmol) and TBDMS chloride (7.54 g, 50 mmol) in dry DME (5 mL) stirred magnetically under dry argon for 110 h. At this point, an aliquot of the supernatant liquid showed 3% unreacted chlorosilane. Workup of the reaction mixture as for HMDT gave **1c** as a pale yellow liquid (4.73 g, 71%), bp 62–66 °C/0.02 Torr, solidifying in the receiver to a solid, mp 39–41 °C. Analysis by GC showed a purity of 99.3%.

Hexaisopropyldisilathiane (1d) from Li_2S and TIPS Chloride

This compound was prepared as for HMDT above from anhydrous Li_2S (0.46 g, 10 mmol) and TIPS chloride (4.28 mL, 20 mmol) in dry DME (4 mL) stirred magnetically under dry argon for 833 h. At this point, an aliquot of the supernatant liquid showed 0.1% unreacted chlorosilane. Workup of the reaction mixture as for HMDT gave **1d** as a pale yellow liquid (2.18 g, 61%), bp 107–109 °C/0.01 Torr, solidifying in the receiver to a solid, mp 38–39 °C. Analysis by GC showed a purity of 97.4%.

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References

1. J. Hu and M. A. Fox, *J. Org. Chem.*, **64**, 4959 (1999).
2. A. Degl'Innocenti, P. Scafato, A. Capperucci, L. Bartoletti, C. Spezzacatena, and R. Ruzziconi, *Synlett*, **4**, 361 (1997) and references therein.
3. A. Capperucci, A. Degl'Innocenti, M. Funicello, G. Mauriello, P. Scafato, and P. Spagnolo, *J. Org. Chem.*, **60**, 2254 (1995).
4. L-L. Lai, P-Y. Lin, W-H. Huang, M-J. Shiao, and J. R. Hwu, *Tetrahedron Lett.*, **35**, 3545 (1994).
5. See, for example, the use of HMDT in the preparation of a novel form of aluminum sulfide: R. J. Wehmschulte and P. P. Power, *J. Am. Chem. Soc.*, **119**, 9566 (1997).
6. T. J. Curphey and H. H. Joyner, *Tetrahedron Lett.*, **34**, 7231 (1993).
7. M. R. Detty and M. D. Seidler, *J. Org. Chem.*, **47**, 1354 (1982).
8. E. Louis and G. Urry, *Inorg. Chem.*, **7**, 1253 (1968).
9. D. A. Armitage, M. J. Clark, A. W. Sinden, J. N. Wingfield, E. W. Abel, and E. J. Louis, *Inorg. Synth.*, **15**, 207 (1974).
10. D. N. Harpp and K. Steliou, *Synthesis*, **11**, 721 (1976).
11. J. E. Drake, B. M. Glavincevski, R. T. Hemmings, and H. E. Henderson, *Inorg. Synth.*, **19**, 274 (1979).
12. E. W. Abel, *J. Chem. Soc.*, 4933 (1961).
13. J. H. So and P. Boudjouk, *Inorg. Synth.*, **29**, 30 (1992).
14. For a claim to have prepared diatomic sulfur by the action of a catalytic amount of NaH on S_8, see: K. Okuma, S. Kuge, Y. Koga, K. Shioji, H. Wakita, and T. Machiguchi, *Heterocycles*, **48**, 1519 (1998).
15. D. Guijarro and M. Yus, *Tetrahedron*, **56**, 1135 (2000) and references therein.
16. For a preparation of HMDT by reduction of thiophene with Li in the presence of TMS chloride, see: M. Laguerre, J. Dunogues, N. Duffaut, and R. Calas, *J. Organomet. Chem.*, **193**, C17 (1980). While this procedure gives a reasonable yield (80%) of HMDT, two-thirds of the metal and of the silyl chloride taken are used in the production of a silylated byproduct originating from the thiophene carbon skeleton. This byproduct must then be removed by subsequent distillation.
17. G.A. Olah, B. G. B. Gupta, S. C. Narang, and R. Malhotra, *J. Org. Chem.*, **44**, 4272 (1979).
18. E. I. Band and S. T. Eberhart, US Patent 4943647 (1990).
19. N. Weidenbruch, A. Schaefer, and R. Rankers, *J. Organomet. Chem.*, **195**, 171 (1980).
20. M. D. Mizhiritskii and V.O. Reikhsfel'd, *Zh. Obshch. Khim.*, **55**, 1537 (1985).